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Innovative reservoir sediments reuse and design for sustainability of the hydroelectric power plants

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A B S T R A C T

In the process of producing hydroelectricity, plants all over the world are faced with the problem of reservoir sediment. If this sediment is removed but not properly disposed of, it can become a secondary pollutant. This study proposes a way to resolve this problem through reuse and recycling.

In this study, the process is based on Design for Six Sigma (DFSS) where reservoir sediment and the masonry waste from the construction industry are combined with cement and a curing agent. The resulting mixture transforms into a high strength, non-sintered cured brick after 28 days of natural curing. This product is a new walling material that is friendly to environment, fulfill the goal of energy conservation, waste recycle, protect ecosystems, and promote sustainable development. Large scale recycling of reservoir sediment solves the problems that reservoir sediment poses, as well as increasing the capacity of reservoirs and the effectiveness of hydroelectric power plants. The green milestone reached by the technology is of great industrial, economic and social significance.

Contents

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1. Introduction

The increasing fossil fuels consumption since the industrial revolution has resulted in massive greenhouse gases in the atmosphere. It results in global warming which has received greater international attention. After the adoption of the Kyoto Protocol and the convening of the Copenhagen Summit, the international response to energy crisis, environmental protection awareness, and the development of new energy sources have become critical issues in the twenty-first century. The development and utilization of renewable energy are important tools to solving the problem of global warming. The term “renewable energy” refers to natural resources that can be replenished continually, such as solar energy, wind energy, geothermal energy, hydro energy, or bioenergy. Finding ways to reduce greenhouse gas emissions and increase the production of renewable energy sources are prerequisites to sustainable development. The long-term use of renewable energy is essential to a nation's competency and sustainability. From an environmental standpoint, renewable energy reduces the risks of climate change associated with the greenhouse gas emissions caused by burning fossil fuels [1]. However, the development of renewable energy in many countries is in its infant stage, and is still in need of much investment in technical, financial, and political resources [2]. At present, costs of renewable energy are higher than those of fossil fuels [3]. Although market penetration of renewable energy has increased, it is still limited, because of the higher production expenses [4] and a lack of public support. Renewable energy needs both an influx of technology and financial subsidies [5]; therefore, governments should employ research and development (R&D) funds and cost subsidies to support the development of renewable energy.

The development of renewable resources requires large amounts of capital because they are much more expensive compared to fossil fuels. Many technologies for renewable energy are immature and the development of renewable resources faces many bottlenecks. Hydro energy and its application on hydroelectricity is the only form of renewable energy that has been in use for over 100 years. Both the technology and the experience of this renewable energy are mature and the cost is relatively low. Table 1 lists ten countries with the most reservoirs. Using China's Three Gorges project as an example, hydroelectric power plants supply power to over half of China and reduces the use of coal and the carbon dioxide emissions by 50 million tons and 30 million tons, respectively.

In the hydroelectric power plants, reservoir sediment is a waste product and has become an environmental concern for all reservoirs worldwide. If sediment is removed but not disposed of properly, it causes secondary pollution to the environment and ecology. If the sediment is properly disposed of by converting it to a reusable resource, it would not only reduce the amount of waste, but also prevent the sediment from becoming a secondary pollutant. This would also serve to conserve energy, which has major contribution in energy consumption. Recycling waste would truly conform to the intent of using renewable resources. Therefore, corporations should consider the green concepts [6].

Recycling waste materials to increase the energy supply should be within the scope of utilizing new energy resources. Internationally, energy conservation is considered as the fifth major source of energy (the other four are coal, oil, renewable energy, and nuclear energy) and is a new method for increasing the supply of energy. Therefore, renewable energy, green energy, and conserving energy all belong to the new energy. Corporations that emphasize innovative green design technology reduce waste and harmful substances as well as highlight their environmental friendliness [7]. Efficient innovative energy production increases the corporation's market value, while enhancing its reputation and environmental performance [8]. Corporations can also improve the competitiveness of their products and their environmental sustainability and development. Wee et al. [9] surveyed the renewable energy supply chains, performance, application barriers and strategies for further development.

Currently, recycling is highly valued. Operational problems arise from trying to integrate recyclable materials from different sources into sustainable processes and remanufacture them into new products [10]. Therefore, to reduce the negative effects of pollution to the environment, corporations should maximize green consumption, recycling processes, waste reduction, and energy conservation.

A novel method to combine reservoir sediment with masonry waste from construction industry into a high value product is described in this study. A new manufacturing process that produces a strong non-sintered cured brick and fulfills the objectives of environmental protection, energy conservation, and waste recycling is discussed.

2. Optimization methods applied to reservoir sediments

In recent years, due to energy crisis and worsening environmental issues, environmental protection and the concept of greening have become very important. Industries have paid more attention to environmental concerns [11]. Various environmental problems have been experienced by reservoirs worldwide due to natural and

Table 1
Ten countries with the most reservoirs.
Source: Water Resources Agency, Ministry of Economic Affairs, R.O.C., 2005.

Country	Number of reservoirs
China	22,000
United States	6,575
India	4,291
Japan	2,675
Spain	1,196
Canada	793
South Korea	765
Turkey	625
Brazil	594
France	569

human-caused factors. Natural factors include fragile geology, steep terrains, fast flow of rivers and steep slopes, typhoons, storms, and earthquakes. Human-caused factors include excessive cultivation, deforestation, indiscriminate building, and new roads. When soil is softened by rain or erosion, it forms muddy water that flows into the reservoir where it settles as reservoir sediment. This leads to a serious problem because the sediment increases quickly; it reduces the capacity of reservoirs, and decreases the lifespan of reservoirs. In addition, the fine silt suspended in the water is difficult to remove and it obstructs the intake pipes of hydroelectric power plants. As a result, it weakens the flood protection mechanisms, and their ability to produce electricity. The costs of removing and disposing the sediment continuously increase, causing environmental problems. Converting the reservoir sediment into an alternative use not only eliminates the secondary pollution, it also serves to conserve energy. This extends the life span of reservoirs and restores their capacities and power levels. Furthermore, the waste reuse sustains environment quality and increases the economical value.

Green production aims for zero pollution, and restricts the conservation of raw materials and energy. Many proposed technologies to reuse reservoir sediment are based on sintering such as building bricks [12]; lightweight aggregate [13–17] and inorganic polymers [18]. The sintering process used in these studies produces CO_2, which causes the secondary pollution to the environment and ecology. This is not an ideal way to recycle waste because it does not achieve the goals of reusing renewable resources. The process described in this study not only resolves the problem of removing and transporting masonry waste, but also solves problem regarding appropriate treatment of reservoir sediment. The elimination of sintering in the production process decreases CO_2 pollution, as well as conserving energy and reducing carbon emissions.

Green design advocates zero waste and green production process at the same time at the product design stage. Most importantly, the impact of the process to the environment should be considered [19–21]. Corporations should prioritize the use of green materials that have higher efficiency, zero pollution, and are easily recyclable [22]. Implementing green manufacturing practices by corporations consists of improving product development, developing new technology, increasing internal efficiency, and more importantly, improving environmental performance. Although many strategies for recycling reservoir sediment have been proposed, none of them has produced a significant result. Raw materials used in this research come from waste products, and the process attempts to fulfill the goal of “zero waste, zero pollution” and to convert waste to resources. Converting reservoir sediment and masonry waste into strong non-sintered cured bricks can reduce the use of cement in construction, thus reducing coal consumption. Solving the problem of reservoir sediment can increase the capacity of reservoirs and improve the effectiveness of hydroelectric power plants. Furthermore, the milestone reached by the technology and production aggregates to great industrial, economic, and social achievement.

3. Green design for Six Sigma design process

Design for Six Sigma (DFSS) is a management methodology used to systematically improve the product design and development process. However, DFSS does not offer a step by step method in new product development. The DFSS project in this study applied the define-measure-analyze-design-verify (DMADV) concept defined by Joseph and Zion [23] as a basic framework of the design process. In addition, the ISO 9001 quality management standards regarding design and development processes were referenced. The design processes used in this study are described as follow:

(1) The five design stages
   (a) Stage 1: Product concept and planning.
   (b) Stage 2: Product design and prototype modeling.
   (c) Stage 3: Product verification.
   (d) Stage 4: Product testing.
   (e) Stage 5: Mass production and product launch.
(2) DMADV
   (a) Define: Define product development project goals, critical themes, and directions.
   (b) Measure: Measure or assess customer needs and critical to quality characteristics (CTQCs).
   (c) Analyze: Analyze functional requirements and CTQCs.
   (d) Design: Design a product that is optimized for customer needs through a process that eliminates or reduces potential defects.
   (e) Verify: Verify that the quality of the designed product meets customer needs.

The design and development stages used in this study and their relationship to the DFSS methodology are shown in Fig. 1.

3.1. Product development practices

(1) Define: All aspects of the design of non-sintered cured bricks are carefully assessed. The primary goals during the design process are reducibility, reliability, innovative performance, and maintainability. Technology and resources are harnessed to create a novel product with simple manufacturing process, easily sourced and improves construction efficiency.
(2) Measure: Non-sintered cured brick is an industrial product unintended for consumers. Therefore, the Kano model was used to analyze customer needs and to evaluate the requirements for customer satisfaction. The purpose of DFSS is design improvement at the source. Based on the Kano model analysis, product design emphasizes attractive and 1D quality to enable the manufacturing technology of bricks and to attain a new green construction, customer satisfaction, and overall synergy.
(3) Analyze: The design of non-sintered cured bricks emphasized attractive and 1D quality as key goals. The following CTQCs were identified: “increases construction efficiency” and “surpasses quality of currently available products.” These CTQCs are transformed into initial product specifications, functions, and technical requirements. After analyzing the procedures, innovative solutions are developed to satisfy functional requirements.
(4) Design: The foundation of the manufacturing process is determined based on a solution chosen after analysis. The “increases construction efficiency” and “surpasses quality of currently available products” of CTQCs are converted into functional requirements. Target values and tolerance are then established. Metrics are defined for functional evaluations. Design failure mode and effects analysis (DFMEA) is performed to evaluate and coordinate risks and improve design quality.
(5) Verify: The verification process refers that the non-sintered cured bricks adhered to environmental and reliability specifications. The product underwent repeat testing and design changes to ensure that it meets customer CTQCs.

3.2. Product development projects

3.2.1. Product concept and planning

The main goals at this stage are to confirm and approve the product plans, and to develop and determine the model of the new product. The main tasks are listed below.

(1) Design input
   (a) Collect data regarding market and customer needs and future market development trends.

- (b) Generate new product ideas.
- (c) Define CTQCs and collecting technical data.
- (d) Satisfy relevant regulatory requirements.
- (e) Obtain other necessary requirements for product development, such as environmental protection, marketing strategies, and business plans.

(2) Design output
- (a) Product plans, including the timeline and budget of product development.
- (b) Product model design.
- (c) Product specifications.
- (d) Feasibility assessment.
- (e) Review meeting for this stage of the design process.

3.2.2. *Product design and prototype modeling*

The main goals at this stage are to complete all advanced product quality planning tasks, verify design feasibility, complete preparatory tasks prior to prototype modeling, and complete the prototype. The main tasks at this stage are listed below.

(1) Design input: The design output from the previous stage is the design input for this stage.
(2) Design output
- (a) Confirmed detailed product specifications and specification requirements.
- (b) Completion of the DFMEA.
- (c) The quality control (QC) project chart for the prototype.
- (d) The bill of materials (BOM) chart for the design.
- (e) Use the design of the experiment to determine the best formula and ratios for the curing agent, reservoir sediment, and cement.
- (f) Select quality acceptance criteria.
- (g) Construct the prototype.
- (h) Review meeting for this stage of the design process.

3.2.3. *Product verification*

The main goals at this stage are to complete confirmation and verification of product design quality and use the results of the mentioned process to modify the product specifications or functions. The main tasks at this stage are listed below.

(1) Design input: The design output from the previous stage is the design input for this stage.
(2) Design output
- (a) Prototype testing and verification report.
- (b) The QC project chart for testing.
- (c) The BOM chart for production.
- (d) The adjusted formula.
- (e) Test the specifications of the product and the specification requirements.
- (f) Review meeting for this stage of the design process.

3.2.4. *Product testing*

The main goals at this stage are to prepare for mass production and conduct a pilot test. The main tasks at this stage are listed below.

(1) Design input: The design output from the previous stage is the design input for this stage.
(2) Design output
- (a) Product testing and verification reports.
- (b) The QC project chart for mass production.
- (c) The modified BOM chart for production.
- (d) The re-adjusted formula.
- (e) Completion of the process failure mode and effects analysis (FMEA).
- (f) Review meeting for this stage of the design process.

3.2.5. *Mass production*

The main goals at this stage are completing minor adjustments to the design based on issues that arose during the product testing and officially launching the mass production of the new product. The main tasks at this stage are listed below.

(1) Design input: The design output from the previous stage is the design input for this stage.
(2) Design output

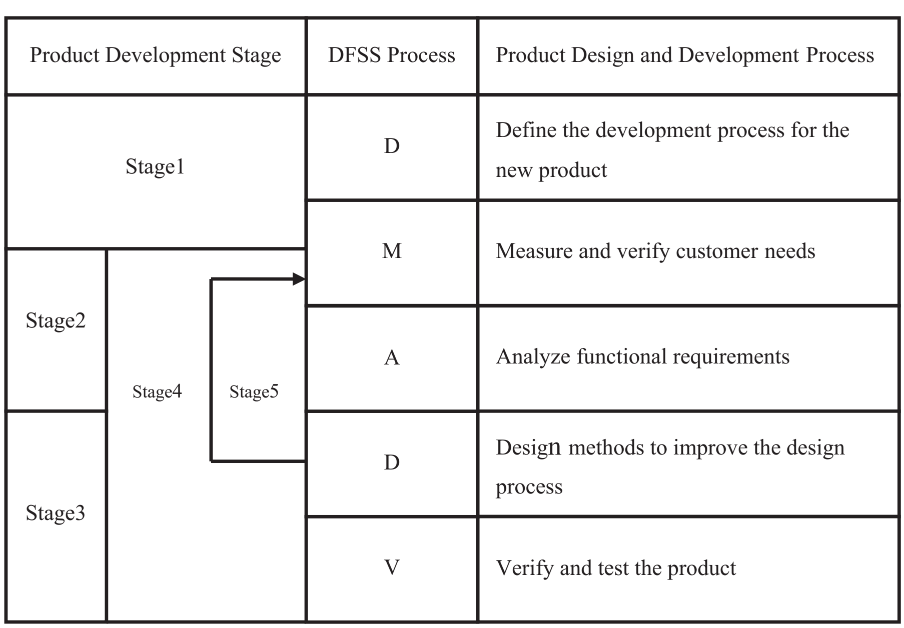

Fig. 1. Relationship between design and development stages and DFSS.

(a) Periodic testing and verification in accordance with specification requirements.
(b) Periodic QC meetings and continuous improvement.
(c) Summary reports of product development.
(d) Mass production of the product.
(e) Review meeting for this stage of the design process.

4. Innovation application

The new manufacturing process described in this study is new, and as far as we know, has not been used before. We have recently received pattern for the innovation. In the innovation, the reservoir sediment and industrial waste are combined to produce non-sintered cured brick. The production cost is low, and the market's demand is high. The estimated overall production is 58 million bricks, and they can be used for both residential and industrial walling.

4.1. Operations system description

Raw materials consist of two major components. The first component is reservoir sediment while the second component is a mixture, which can be composed from any uncontaminated solid, including masonry waste, or demolition waste, stone dust from rock processing, coal slag, mine tailings, or any texture soil from mountains, dirt, or sea. This process uses large amounts of reservoir sediment and construction or mining waste and is an effective method for recycling waste. The two components are crushed and a curing agent is added. Cement is used as the binding material. After adding water and dry-hard stirring are performed, the product is molded under high pressure. After 28 days of natural conservancy, the non-sintered cured bricks can be used in both weight-bearing and non-weight-bearing structures. The process is illustrated in Fig. 2.

- The curing agent is a composite of many organic and inorganic materials and is a new low-energy, environmentally friendly construction material. The amount of curing agent depends on the physical and chemical characteristics of the soil being cured. After mixing and compacting procedures, cement with the required characteristics is produced. The material ratios can be adjusted to find an optimal formula for construction, depending on environmental and quality standards.
- The high pressure molding machine has superior characteristics. It can produce bricks of concrete mixtures, similar to other brick molding machines, but it does not use pallets. The outcomes show that the proposed product can decrease the fixed capital by 25%, reduce labor costs by 30%. Further, production efficiency is improved by 40%. Its molds can produce many special shaped bricks which cannot be done by the current models. This machine is ahead of its time in terms of brick molding.

4.2. Product characteristics

This product has been tested in multiple constructions, and its excellent characteristics and cost advantages have been confirmed. More specific characteristics are described as follows.

(1) The raw material can come from a wide range of sources and is not restricted to any particular source. It can be composed from any uncontaminated solid, including masonry waste or demolition waste, stone dust from rock processing, slag, mining tailings, and any texture soil from mountains, land, or sea. This process can effectively recycle large amounts of reservoir sediment and construction waste or mining waste.
(2) The process is easily implemented. The product is mixed with cement, molded under high pressure, and then placed in a yard for 28 days for natural conservancy. The brick is then ready to be used. It does not need to be sintered, steam cured, or water cured. This conserves energy and produces no CO_2 or any other waste. Therefore, it is friendly to environment.
(3) It shows superior performance and low water absorption. It does not require wetting before plastered or other uses in construction. The bricks are uniformly flat and thus take less mortar. Because it is water repellant, it is ideal for outside wall without plastering. This saves the cost of waterproofing materials. In addition, it is soft enough to be directly nailed into and easy to score. It is easily transported without damage and efficient material in construction.
(4) Using this product can improve 50% of the efficiency of construction projects. The amount of mortar used is 50% less. It requires less water, is faster to plaster, and is easy to cut. As a result, it will reduce cost, and become a popular construction product.

4.3. Verification of the product design

This product was tested by China's National Center for Quality Supervision and Test of Building Engineering. The results are listed below.

4.3.1. Density

The density of a clay bricks is approximately 1920 kg/m^3, but clay bricks are prone to chalking. Chalking reduces density and increases water absorption, which can cause efflorescence. The density of non-sintered cured bricks is shown in Table 2. It has higher density and lower water absorption than red bricks. It does not require wetting before it can be plastered or other uses in

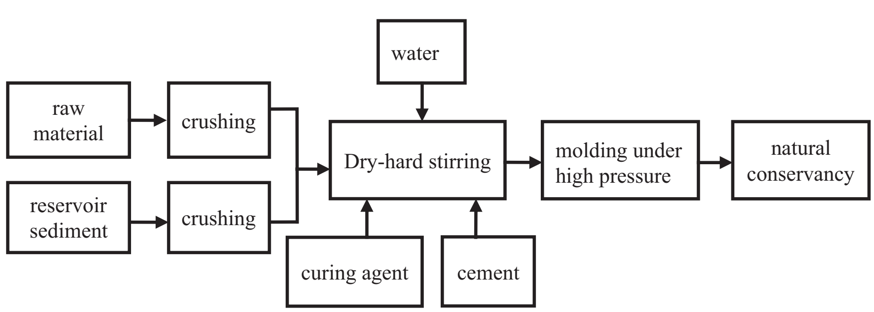

Fig. 2. Manufacturing process.

construction. It is water repellant and fit for outer walls without plastering, which eliminates the need for waterproofing materials.

4.3.2. Compressive strength

The compressive strength of a grade A–A brick is approximately 14.5 MPa, and a grade A brick is approximately 9.8 MPa. The compressive strength of non-sintered cured bricks is listed in Table 3.The strength grade of the developed product is significantly higher than that of the grade A–A bricks.

4.3.3. Water absorption

The water absorption of clay brick is approximately 14%. Before bricklaying, bricks should be wetted to avoid dry bricks leaching water from the mortar, which can cause the mortar to crack or separate from drying too fast. The water absorption of non-sintered cured bricks is shown in Table 4. It is significantly lower than the commonly used bricks.

4.3.4. Dry shrinkage and relative moisture content

The higher the moisture content in a brick, the more shrinkage can occur. Clay brick dry shrinkage is between 0.04% and 0.07%. By controlling the moisture content, dry shrinkage can be controlled. The dry shrinkage and relative moisture content of non-sintered cured bricks are shown in Table 5.

4.3.5. Frost resistance

Frost resistance is achieved when bricks do not exhibit signs of cracking, spalling, delaminating, or crumbling edges after 15 freeze/thaw cycles, the total loss in weight is less than 2%, and the strength is reduced by less than a defined value. The frost resistance of non-sintered cured bricks is listed in Table 6.

Table 2
Density of non-sintered cured bricks.

Density grade	Average of 3 units
A	≧2100
B	1681–2099

Unit: kg/m^3.

Table 3
Compressive strength of non-sintered cured bricks.

Strength grade	Compressive strength	
	Average	Minimum
MU40	≧40.0	≧35.0
MU35	≧35.0	≧30.0
MU30	≧30.0	≧26.0
MU25	≧25.0	≧21.0
MU20	≧20.0	≧16.0

Unit: MPa.

Table 4
Water absorption of non-sintered cured bricks.

Water Absorption of Different Density Bricks (average of 3 units)	
≧2100 kg/m^3(Grade A)	1681–2099 kg/m^3(Grade B)
≦8	≦10

Unit: %.

4.3.6. Carbonation coefficient and softening coefficient

Both carbonation coefficient and softening coefficient should be greater than 0.80. Carbonation coefficient is a number obtained by testing for the carbonation depth that is used to adjust the rebound number. Softening coefficient is a performance indicator of water resistance. It is in the range of 0 and 1, and the higher the number, the more water resistant a material is. The carbonation coefficient and the softening coefficient of non-sintered cured bricks are both greater than .80.

4.3.7. Size variations

The standard size of non-sintered cured bricks is 240 mm × 115 mm × 53 mm. The permissible variation for length is ±2 mm. The permissible variation for width is ±1.5 mm. The permissible variation for height is ±1.5 mm.

4.3.8. Appearance and quality

The appearance and quality specifications for non-sintered cured bricks are shown in Table 7.

5. Managerial implications

By comparing the results of this study and the existing management theory, the following managerial implications are derived.

5.1. Competitive strategy of creating value through innovation

Because changes in global business environment are unpredictable and possess tremendous risk and uncertainty, sustainability management might no longer be the ultimate objective of corporations. Continuous innovation, value creation, and pursuit of profit aim to increase corporate growth and competitiveness in order to ensure survival [24]. Therefore, employing innovations to create value and increase competitiveness [25] is what differentiates non-sintered cured bricks from other products. Corporations that only rely on low labor costs to survive will be unable to maintain their competitive advantage in the long term. Innovations are the force behind the company's competitive advantage. Corporations with good innovation and control costs have the

Table 5
Dry shrinkage and relative moisture content of non-sintered cured bricks.

Shrinkage	Relative moisture content (average of 3 units)		
	Humid	Intermediate	Arid
≦0.03	≦45	≦40	≦35

Unit: %.
Note 1: Relative moisture content is the comparison between moisture content and moisture absorption of non-sintered cured bricks.
Note 2: Annual humidity of the area where bricks are used.
Humid: An area where the average annual relative humidity is greater than 75%.
Intermediate: An area where the average annual relative humidity is between 50% and 75%.
Arid: An area where the average annual relative humidity is less than 50%.

Table 6
Frost resistance of non-sintered cured bricks.

Climate conditions	Frost resistance index	Loss in weight	Loss of strength
Subtropical region	F15	≦2.0	≦20
Tropical region	F25		
Continental region	F35		
Sub-polar region	F50		

Unit: %.

Table 7
Specifications for appearance and quality of non-sintered cured bricks.

Characteristic		Variation
Difference in surface height	Not greater than	2
Curvature	Not greater than	1
Chipping of any 3 sides	Not simultaneously Greater than	5
Length of cracks	Not greater than	5
Unblemished surface	Not less than	One top surface and one side surface

Unit: mm.
The presence of either of these defects disqualifies a surface as unblemished.
(1) A defect larger than 5 mm × 5 mm.
(2) A crack wider than 1 mm and longer than 10 mm.

greatest advantage in the future industrial development. Numerous corporations rely on innovative products and technology to compete. However, due to the development of technology; corporations with lower prices and better quality have higher chance to success. Thus, successful corporations create new unrivaled markets at the outskirts of existing industries, developing unique technologies and operational models that are difficult to replicate, and thus obtaining long-term competitive advantage.

The growth of dominating industry is independent of the size of corporations, the abundance or scarcity of resources, or market share, but is dependent on the ability to understand future market opportunities. The non-sintered cured bricks developed in this study were created using novel technology that produces construction materials from reservoir sediment and construction waste. The bricks exhibited superior performance, easy to produce, conveniently sourced, low-cost, non-polluting, and the production technology is unique. The core capabilities of the developed bricks are difficult to imitate by competitors. This brings the company's business opportunities and profits.

The key elements to the successful development of the non-sintered cured brick include the following.

(1) High-level executive participation and support at the new product development stage was critical. In our case study, the executives were trained in engineering and willing to accept product innovation risks. They understood the importance of new product development process, and actively support the new product development by involving in the vital strategic decisions personally.
(2) The corporation in this case study had a comprehensive strategy for new products, with clearly defined roles for innovative R&D. This provides sufficient momentum for the product development plan.
(3) For the product development process, the establishment of cross-functional team and identification of the precedence and duration of project tasks were helpful. Hence, the project can meet the due date of customers.
(4) The research direction received strong governmental support. The technology adopted in this study was considered as a key innovative technology by the Chinese government in 1999. In 2007, the technology was adapted to civil products. In 2010, non-sintered cured bricks officially underwent production and widely accepted in the market.

5.2. Industrial revolution of green renewable building materials

Since global ecosystems face serious deterioration, and the awareness of environmental protection is growing, enterprises with corporate social responsibility must apply the green philosophy to integrate environmental protection activities into all facets of their daily operations, and to develop strategies that transform environmental threats into environmental protection opportunities. Although the need for environmental protection places great pressure on corporations, they could turn risks into opportunities by adopting proactive environmental protection strategies; thereby attain greater opportunities to grow. In the past, numerous corporations only considered the costs associated with environmental protection and overlooked the benefits offered by green technology innovations. Therefore, current industries should focus on using sustainable-oriented innovation systems [26] to create environmentally safe technology. Corporations should apply the concepts of green innovation in R&D, design, production, and marketing to reduce negative impacts on the environment and create value and profit opportunities for the corporation. Recycling and reducing waste, energy conservation, carbon reduction, and sustainable development have became crucial concerns for governments in their implementation of environmental protection policies. It effectively transforms waste materials into usable recycled products without causing pollution and provides opportunity for corporations to create high value-added products.

In Taiwan for example, the annual amount of waste concrete blocks is estimated at 63.9 million metric tons. Careless disposal of this demolition waste engenders serious environmental pollution and ecological catastrophes. Current disposal technology is costly and CO_2 emissions that cause the secondary pollution. The Shihmen Dam in Taiwan, for instance, has approximately 90 million m^3 of reservoir sediment, which increases at an annual rate of 4 million m^3. The original dam capacity was 3.1 trillion m^3 and has been reduced to 2.1 trillion m^3 (nearly one third of the total capacity) in just 3 decades. This example demonstrates a serious problem incurred by reservoir sediment for dams. At the current rate of dredging (500,000 m^3 per year), it will take approximately 188 years to remove all reservoir sediment in the Shihmen Dam. Enormous expense is spent each year to dredge the dam. Waste transportation causes significant environmental issues. Current recycling technology requires sintering, which produces CO_2 and causes to the secondary contamination to the environment. However, the current treatment of reservoir sediment and construction waste does not manage waste adequately. Therefore, it fails to achieve renewable resource use. This study introduced non-sintered cured bricks, which use reservoir sediment as the primary raw material mixed with construction waste, and employed an innovative technique to produce green construction material. In addition to substantially reduce the burden on the environment and related costs incurred by reservoir sediment and construction waste, non-sintered cured bricks is proposed to improve the corporate image and offer added value.

6. Conclusion

Producing non-sintered cured bricks from reservoir sediment and construction waste simultaneously disposes two types of waste: reservoir sediment from hydroelectric plants, and construction waste that cannot be disposed. This new material can be classified as a green material because it fulfills the goals of greening, environmental protection, recycling, and energy conservation. Therefore, producing a green building material from reservoir sediment and construction waste provides economic benefits and significantly lowers the environmental costs.

The recycled and environmental friendly non-sintered cured bricks are new walling materials that conserve energy, water, improve land and materials use. It also benefits the society by

providing economic value and protecting ecosystems. The successful business model described in this study can solve the long term sediment problem of hydroelectric plants. Future research can be done to consider a business model that will facilitate an environmental-friendly technology to promote an increasing value added business opportunities.

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